Thus, the initial mode discussed with respect to FIG. 5 enables each of the channel receivers to rapidly determine a pre-coder function suitable for reducing transmission channel impairments and channel cross-talk impairments. The amount of data to be processed to determine appropriate pre-coder operating parameters is significant, and that the latency inherent in transmitting error data, initial pre-coder parameters and the like from the receiver to the transmitter may also be time consuming. By implementing a receiver-side training process, and providing to the transmitter a relatively good estimate of transmission-side pre-coder parameters at one time (rather than incrementally as the error rates drop), the training time necessary to reduce transmission channel impairment is greatly reduced.

In a preferred embodiment, initial pre-coder parameters are determined at each receiver based upon the reception of a predetermined training sequence, per FIG. 5. After the initial pre-coder parameters are determined, the determined parameters are provided to the respective transmitters, where they are incorporated into the transmitter side pre-coder functions. In this manner, the transmitter-side pre-coders are rapidly trained to at least an initial state. Since channel impairment characteristics change over time, and since initial parameter selection intended to reduce channel impairments is likely to be imperfect, it is preferable to periodically update transmitter side pre-coder operating parameters, per FIG. 4.

Transmitter-side initial pre-coder operating parameters and/or new error data useful in determining pre-coder parameters is propagated back to the transmitter via in-band or out-of-band transmission means, such as known to those skilled in the art.

Discussion of Pre-Coder Operation

The pre-coders are modeled as complex input, complex output, symbol spaced FIRs. There are 12 pre-coders in this four-user system. Each pre-coder has, illustratively, three complex tap coefficients that are adaptive. To describe the detail of operation of the pre-coder, we first define a

vector, as follows:

$$\mathbf{a}^t(n) = [a(n), a(n-1), a(n-2)] \qquad \text{(equation 8)}$$

as the vector of complex symbols in the delay line at the *n*-th sampling instant, and

$$\mathbf{c}^T(n) = [c_0(n), c_1(n), , c_2(n)] \qquad \text{(equation 9)}$$

as the vector of complex tap coefficient at t he *n*-th sampling instant.

Using superscript *(ij)* to associate with the pre-coder $P_{ij(f)}$, the complex output of each pre-coder can be expressed in vector form as

$$u^{(ij)}(n) = \mathbf{c}^{(ij)^T}(n)\mathbf{a}^{(j)}(n) \qquad \text{(equation 10)}$$

The inputs to the transmit shaping filters are

$$\begin{aligned} v^{(1)} &= a^{(1)}(n) + u^{(12)}(n) + u^{(13)}(n) + u^{(14)}(n) \\ v^{(2)} &= a^{(2)}(n) + u^{(21)}(n) + u^{(23)}(n) + u^{(24)}(n) \\ v^{(3)} &= a^{(3)}(n) + u^{(31)}(n) + u^{(32)}(n) + u^{(34)}(n) \\ v^{(4)} &= a^{(4)}(n) + u^{(41)}(n) + u^{(42)}(n) + u^{(43)}(n) \end{aligned} \qquad \text{(equation 11)}$$

The tap coefficients of pre-coder $P_{ij(f)}$ are updated as

$$\begin{aligned} c_0^{(ij)}(n+1) &= c_0^{(ij)}(n) - \mu a^{(j)}(n-D)e^{(j)}(n-D) \\ c_1^{(ij)}(n+1) &= c_1^{(ij)}(n) - \mu a^{(j)}(n-D-1)e^{(j)}(n-D-1) \\ c_2^{(ij)}(n+1) &= c_2^{(ij)}(n) - \mu a^{(j)}(n-D-2)e^{(j)}(n-D-2) \end{aligned} \qquad \text{(equation 12)}$$

where μ is the update step size, $e^j(n)$ the complex error obtained at the slicer of receiver *j* by subtracting the transmitted symbol $a^j(n)$ from the sampled symbol $a^{ij}(n)$ at the receiver, and *D* is the delay in number of symbol intervals from the time $a^{ij}(n)$ enters the pre-coder to the time the corresponding error is available at t he slicer of receiver *j*. The various parameters may be determined using the least mean square (LMS) algorithm.

It is noted that symbol streams having relatively fewer amplitude levels may be initially communicated to the receiver. For example, in one embodiment initially communicated symbol streams comprise CAP signals

having only four amplitude points. By communicating a CAP signal having fewer levels during a training period, the receiver 108 can process the received CAP signal in a shorter amount of time. In this manner, initial communications after system turn-up may be used to train the communication channels in a relatively coarse manner. Subsequent increasing CAP signal levels may be used to progressively "fine train" the channels. It will be appreciated by those skilled in the art that although a CAP signal having four points is described within the context of an initial training period, the invention can be readily modified to include more than or less than four points. Moreover, the invention can be modified to use other modulation schemes.

Each of the transmitted symbol streams is received by a respective receiver where it is processed to determine a deviance from an expected received symbol stream. The deviation from an expected symbol stream may be conveyed in terms of a mean square error in a preassigned wave shape or preassigned signal level. It is noted that other error-indicative parameters are well known to those skilled in the art and may be advantageously employed within the context of the present invention. Additionally, other error measurements directed towards deviations induced by problems other than far-end cross-talk may be employed. In any event, the different errors determined by the receivers are propagated back through the communication system to the transmitters.

In one embodiment, the difference error data associated with each of the one or more pre-coded symbol streams is evaluated to determine whether the amount of error or deviance determined by the respective receiver exceeds a desirable or threshold level. If the amount of error is not less than the desired/threshold level, then the corresponding pre-code matrix or matrices of the one or more symbol streams is responsively adapted. If the difference error data is less than the desired threshold level, then the signal level of at least one of the one or more symbol streams is increased. That is, in the case of a CAP symbol stream, the amplitude levels of the CAP signals